Programmable Pulse-Position-Modulation Encoder

NASA's Jet Propulsion Laboratory, Pasadena, California

A programmable pulse-position-modulation (PPM) encoder has been designed for use in testing an optical communication link. The encoder includes a programmable state machine and an electronic code book that can be updated to accommodate different PPM coding schemes. The encoder includes a field-programmable gate array (FPGA) that is programmed to step through the stored state machine and code book and that drives a custom high-speed serializer circuit board that is capable of generating subnanosecond pulses. The stored state machine and code book can be updated by means of a simple text interface through the serial port of a personal computer.

This work was done by David Zhu and William Farr of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-41103, volume and number of this NASA Tech Briefs *issue, and the page number.*

Wavelength-Agile External-Cavity Diode Laser for DWDM

Lyndon B. Johnson Space Center, Houston, Texas

A prototype external-cavity diode laser (ECDL) has been developed for communication systems utilizing dense wavelength-division multiplexing (DWDM). This ECDL is an updated version of the ECDL reported in "Wavelength-Agile External-Cavity Diode Laser" (LEW-17090), *NASA Tech Briefs*, Vol. 25, No. 11 (November 2001), page 14a. To recapitulate: The wavelength-agile ECDL combines the stability of an external-cavity laser with the wavelength agility of a diode laser. Wavelength is modulated by modulating the injection current of the diode-laser gain element. The external cavity is a Littman-Metcalf resonator, in which the zeroth-order output from a diffraction grating is used as the laser output and the first-order-diffracted light is retroreflected by a cavity feedback mirror, which establishes one end of the resonator. The other end of the resonator is the output surface of a Fabry-Perot resonator that constitutes the diode-laser gain element. Wavelength is selected by choosing the angle of the diffracted return beam, as determined by position of the feedback mirror. The present wavelength-agile ECDL is distinguished by design details that enable coverage of all 60 channels, separated by 100-GHz frequency intervals, that are specified in DWDM standards.

This work was done by Jeffrey S. Pilgrim and David S. Bomse of Southwest Sciences, Inc., for **Johnson Space Center**.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to MSC-23408, volume and number of this NASA Tech Briefs *issue, and the page number.*

Pattern-Recognition Processor Using Holographic Photopolymer

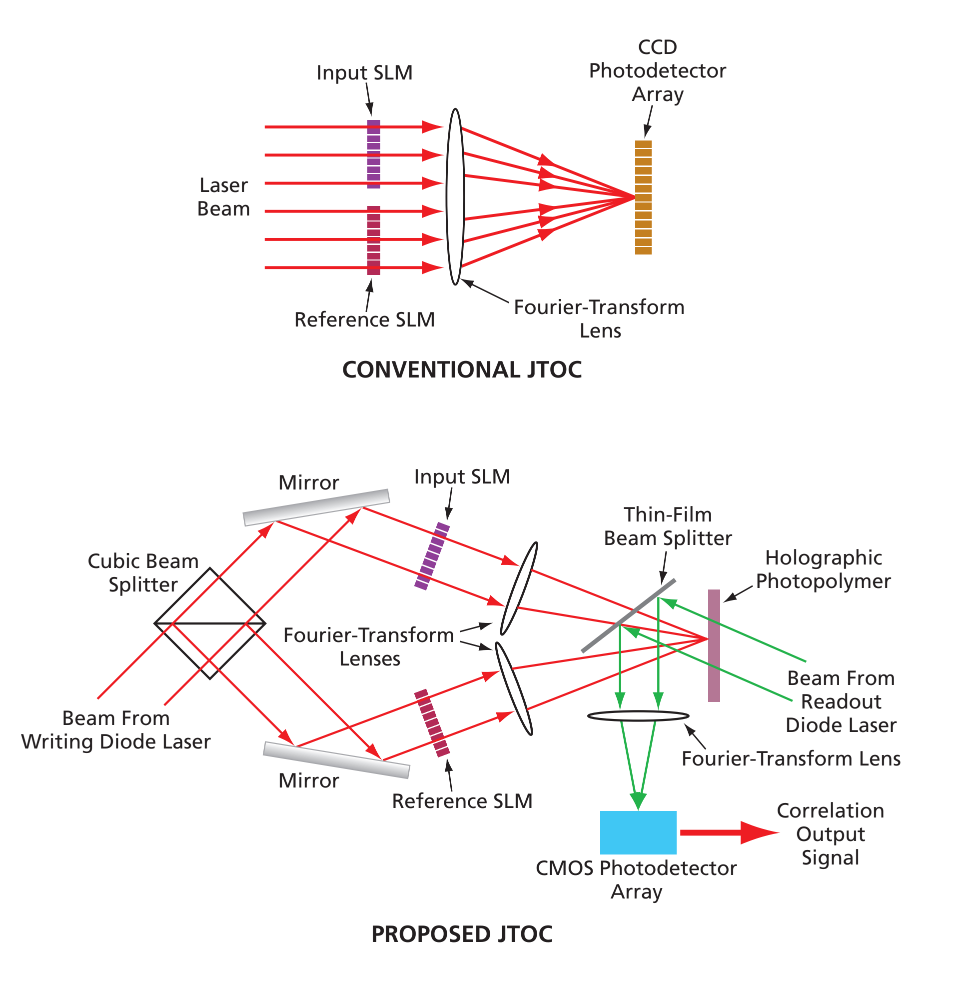
This processor would operate in real time with high resolution.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed joint-transform optical correlator (JTOC) would be capable of operating as a real-time pattern-recognition processor. The key correlation-filter reading/writing medium of this JTOC would be an updateable holographic photopolymer. The high-resolution, high-speed characteristics of this photopolymer would enable pattern-recognition processing to occur at a speed three orders of magnitude greater than that of state-of-the-art digital pattern-recognition processors. There are many potential applications in biometric personal identification (e.g., using images of fingerprints and faces) and nondestructive industrial inspection.

In order to appreciate the advantages of the proposed JTOC, it is necessary to understand the principle of operation of a conventional JTOC. In a conventional JTOC (shown in the upper part of the figure), a collimated laser beam passes through two side-by-side spatial light modulators (SLMs). One SLM displays a real-time input image to be recognized. The other SLM displays a reference image from a digital memory. A Fourier-transform lens is placed at its focal distance from the SLM plane, and a charge-coupled device (CCD) image detector is placed at the back focal plane of the lens for use as a square-law recorder.

Processing takes place in two stages. In the first stage, the CCD records the interference pattern between the Fourier transforms of the input and reference images, and the pattern is then digitized and saved in a buffer memory. In the second stage, the reference SLM is turned off and the interference pattern is fed back to the input SLM. The interference pattern thus becomes Fourier-transformed, yielding at the CCD an image representing the joint-transform correlation between the input and reference images. This image con-



Conventional and Proposed JTOCs differ in geometry and in the media (CCD versus holographic photopolymer) used to record holograms.

tains a sharp correlation peak when the input and reference images are matched.

The drawbacks of a conventional JTOC are the following:

- The CCD has low spatial resolution and is not an ideal square-law detector for the purpose of holographic recording of interference fringes. A typical state-of-the-art CCD has a pixel-pitch limited resolution of about 100 lines/mm. In contrast, the holographic photopolymer to be used in the proposed JTOC offers a resolution > 2,000 lines/mm. In addition to being disadvantageous in itself, the low resolution of the CCD causes overlap of a DC term and the desired correlation term in the output image. This overlap severely limits the correlation signal-to-noise ratio.
- The two-stage nature of the process limits the achievable throughput rate. A further limit is imposed by the low frame rate (typical video rates) of low- and medium-cost commercial CCDs.

In the proposed JTOC, shown in the lower part of the figure, a collimated beam (denoted the writing beam) from a diode laser would first be split into two orthogonal parts that would then be reflected at oblique angles. As in the conventional JTOC, one part of the beam would illuminate an input SLM while the other part would illuminate a reference SLM. In this case, however, there would be two Fourier-transform lenses: one for the input image and one for the reference image. The input and reference beams would intersect at the center of the Fourier-transform plane. A holographic photopolymer film would be placed in this plane for recording the interference fringes.

A second diode laser would generate a readout light beam incoherent with the writing beam (optionally at approximately the same or a different wavelength). The readout beam would illuminate the holographic photopolymer film from the side opposite that of the writing beam. A thin-film beam splitter would be placed between the input Fourier-transform lens and the photopolymer film to intercept the readout beam as modified by passage through the photopolymer film. The modified readout beam would be reflected by this beam splitter, then a third Fourier-transform lens would focus this beam to a correlation output image on a complementary metal oxide/semiconductor (CMOS) photodetector array. When the input scene contained a target image matching the reference image, a sharp correlation peak would appear at the location of the centroid of the input image.

The high-speed-recording and low-data-retention-time characteristics of the photopolymer would make it possible to record holograms in real time repeatedly by use of pulsing of the writing laser in synchronism with updating of the images on the SLMs, while reading out the correlation image continuously by use of continuous operation or synchronous pulsing of the readout laser. The off-axis nature of the holographic-recording geometry of the proposed JTOC would confer an additional advantage that is not intuitively obvious but can be discerned by examination of the equations describing the holographic process: The geometry would give rise to a spatial separation of cross-correlation and convolution components of the output image, such that, as desired, the CMOS photodetector array would retrieve only the correlation component.

This work was done by Tien-Hsin Chao and Kevin Cammack of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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